Real-Time Systems

Lecture 4

Scheduling basics

Task scheduling - basic taxonomy
Basic scheduling techniques
Static cyclic scheduling

Last lecture (3)

Real-time kernels

- The **task states**
  - States and transition diagram
- The **generic architecture** of a RT kernel
- The basic components of a RT kernel, its structure and functionalities
- Some examples: RTKPIC18, SHaRK and XENOMAI

Temporal complexity

- Measurement of the **growth** of the **execution time** of an algorithm as a function of the **problem size** (e.g. the number of elements of a vector, the number of tasks of a real-time system)
- Expressed via the **O( ) operator (big O notation)**
- O( ) arithmetic, n=problem dimension, k=constant
  - $O(k) = O(1)$
  - $O(kn) = O(n)$
  - $O(k_1n^m+k_2n^{m-1}+...+k_{m+1}) = O(n^m)$

```
for (k=0;k<N;k++)
   a[k]=0;
```

Compl. = $O(N)$

```
for (k=0;k<N-1;k++)
   for (m=k;m<N;m++)
      if a[k]<a[m]
           swap(a[k],a[m]);
```

Compl. = $O(N^2)$

Computation of the permutations of a set $A=\{a_i, i=1..N\}$

Compl. = $O(N^N)$

just another example

just another example

Temporal complexity

What is the complexity of scheduling tasks?

- Build **all** possible **schedules** with **two tasks**.
  - E.g.

    {1,2}

    {2,1}
- Build all possible schedules with **3 tasks**.
- Build all possible schedules with **4 tasks**.

Comments ...

Temporal complexity

P and NP classes in decision problems

- **P** – problem that can be solved in polynomial time, O(p(N))
- **NP** – problem that cannot be solved in polynomial time but for which a solution can be tested in polynomial time
    - **NP-complete**
        - No “quick” solutions are known.
    - **NP-hard**
        - At least as hard has NP, but not necessarily of NP type.

The temporal complexity is an important measurement of the performance of algorithms (e.g. scheduling algorithms)

Scheduling Definition

Task scheduling

- Sequence of task executions in one or more processors
- Application of R^+ (time) in N_0^+ (task set), assigning to each time instant "t" a task "i" that executes in that time instant.

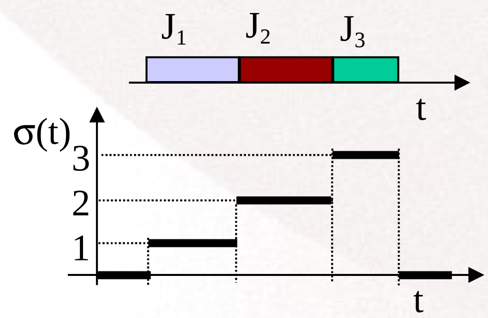
$$\sigma: R^+ \rightarrow N_0^+$$

$$i = \sigma(t),\ t \in R^+ \qquad (i=0 \Rightarrow \text{idle processor})$$

$\sigma(t)$ is a step function, that has the form of a *Gantt graph*

$J=\{J_1, J_2, J_3\}$

(task set) →



Scheduling Definition

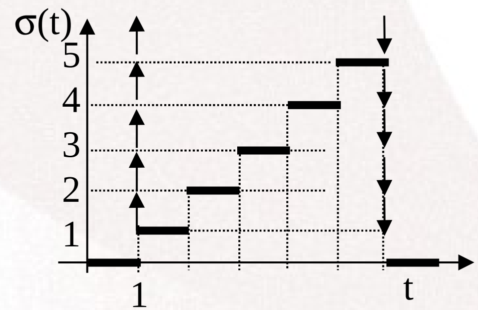
- A schedule is called **feasible** if it **fulfills** all the **task requirements**
  - **temporal**, non-preemption, shared resources, precedences, ...

- A task set is called **schedulable** if there is **at least one feasible schedule** for that task set

The scheduling problem
(easy to formulate, hard to solve)

- **Given:**
  - A **task set**
  - **Requirements** of the tasks (or cost function)
- **Find a time attribution of processor(s) to tasks so that:**
  - **Tasks are completely executed,** and
  - **Meet they requirements** (or minimize the cost function)

e.g. $J = \{J_i\ (C_i=1,\ a_i=1,\ D_i=5,\ i=1..5)\}$ →



just another example

just another example

Scheduling problem

- Build a Gantt diagram of the execution of the following periodic tasks, admitting $D_i=T_i$ and no preemption.
  - $\tau=\{(1,5)(6;10)\}$
- Is the execution order important? Why?

Scheduling algorithms

- A scheduling algorithm is a method for **solving** the scheduling problem.
  - **Note:** don't confuse scheduling algorithm (the process/method) with schedule (the result)
- Classification of scheduling algorithms:
  - **Preemptive** *vs* **non-preemptive**
  - **Static** *vs* **dynamic**
  - ***Off-line*** *vs* ***on-line***
  - **Optimal** *vs* **sub-optimal**
  - With **strict guarantees** vs **best effort**

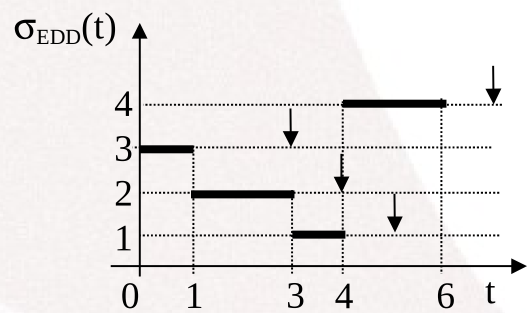
Basic algorithms

EDD - Earliest Due Date (Jackson, 1955)

- Single instance tasks fired synchronously:
  $J = \{ J_i (C_i, (a_i=0,) D_i) \ i=1..n\}$
- Executing the tasks by **non-decreasing deadlines minimizes the maximum latency** $L_{max}(J) = \max_i (f_i - d_i)$
- Complexity: **O(n.log(n))**

e.g. $J = \{J_1(1,5), J_2(2,4), J_3(1,3), J_4(2,7)\}$

$L_{max,EDD}(J) = -1$



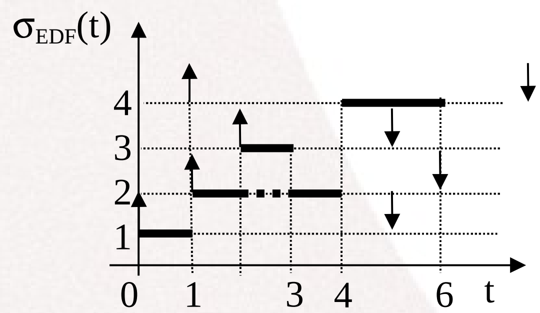
Basic algorithms

<u>**EDF - Earliest Deadline First**</u> (Liu and Layland, 1973; Horn, 1974)

- Single instance or periodic, asynchronous arrivals, preemptive: $J = \{ J_i (C_i, a_i, D_i)\ i=1..n)\}$
- Always **executing** the task with **shorter deadline** minimizes the maximum latency $L_{max}(J) = max_i (f_i - d_i)$
- Complexity: **O(n.log(n)),** **Optimal** among all scheduling algorithms of this class

e.g. $J = \{J_1(1,0,5), J_2(2,1,5), J_3(1,2,3), J_4(2,1,8)\}$

$L_{max,EDF}(J) = -2$

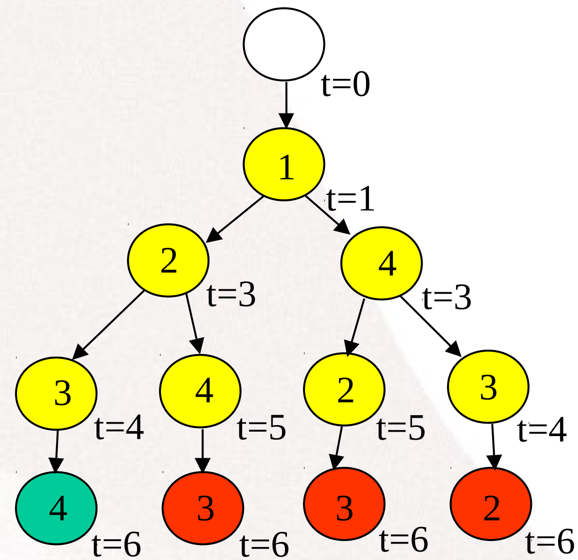


Basic algorithms

BB – Branch and Bound (Bratley, 1971)

- Single instance or periodic tasks, asynchronous arrivals, non-preemptive: $J = \{ J_i (C_i, a_i, D_i)\ i=1..n\}$
- Based on building an exhaustive search in the permutation tree space, finding all possible execution sequences:
- Complexity: **O(n!)**

e.g. $J = \{J_1(1,0,5), J_2(2,1,3), J_3(1,2,4), J_4(2,1,7)\}$



Periodic task scheduling

The release/activation instants are known a priori

$\Gamma = \{ \tau_i \, (C_i, \Phi_i, T_i, D_i, \; i=1..n)\}$; $a_{i,k} = \Phi_i + (k-1)T_i$, $k=1,2,...$

<u>Thus, in this case the schedule can be built:</u>

- **With the system executing (*on-line*)**
  Tasks to execute are selected as they are released/finished, during normal system operation
- **Before the system enters in execution (*off-line*)**
  The task execution order is computed before the system enters in normal operation and stored in a table, which is used at execution time to execute the tasks (**static cyclic scheduling**).

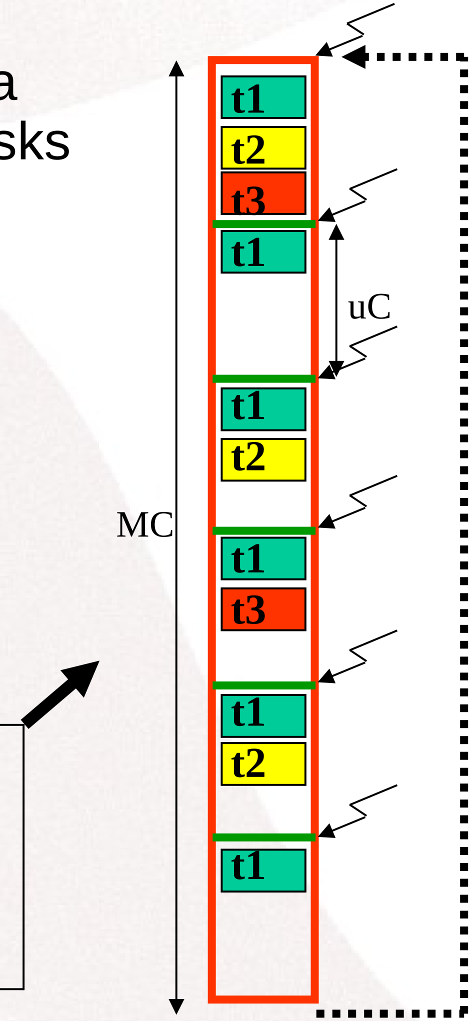
Static cyclic scheduling

- The table is organized in **micro-cycles (μC)** with a fixed duration. This way it is possible to release tasks periodically
- The micro-cycles are triggered by a **Timer**
- Scanning the whole table repeatedly generates a periodic pattern, called **macro-cycle (MC)**

$\Gamma = \{ \tau_i \ (C_i, \Phi_i, T_i, D_i, \ i=1..n)\}$

μC = GCD(T_i) (*GCD*)
MC = MCM(T_i) (*LCM*)

$\Phi_i = 0$, $C_i = 1$ms,
$T_1 = 5$ms
$T_2 = 10$ms
$T_3 = 15$ms



Static cyclic scheduling

Pros

- Very simple implementation (timer+table)
- *Execution overhead* very low (simple dispatcher)
- Permits complex optimizations
  (e.g. jitter reduction, check precedence constraints)

Cons

- Doesn't scale (changes on the tasks may incur in massive changes on the table. In particular the table size may be prohibitively high)
- Sensitive to overloads, which may cause the “domino effect”, i.e., sequence of consecutive tasks failing its deadlines due to a bad-behaving task.

Static cyclic scheduling

How to build the table:

- Compute the micro and macro cycles (µC and MC)
- Express the periods and phases of the tasks as an integer number of micro-cycles
- Compute the cycles where tasks are activated
- Using a suitable scheduling algorithm, determine the execution order of the ready tasks
- Check is all tasks scheduled for a give micro-cycle fit inside the cycle. Otherwise some of them have to be postponed for the following cycle(s)
- It may be necessary to break a task in several parts, so that that each one of them fits inside the respective micro-cycle

Summary of Lecture 5

- The concept of **temporal complexity**
- Definition of **schedule** and **scheduling algorithm**
- Some basic **scheduling techniques** (EDD, EDF, BB)
- The **static cyclic scheduling** technique